Surf Zone Reconnaissance Project

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LONG-TERM GOAL

The goal of the project is to develop practical sensors and algorithms to allow small, crawling robots to autonomously detect and classify objects in the surf zone minefields, initially as threat-no-threat, and later as object type. These sensors will be key to performing lane exploration, lane mapping, and other missions using autonomous robots.

OBJECTIVES

The initial objective is to demonstrate autonomous detection of mine-like objects using simple physical contact and material sensing techniques, and to transmit an image of each target for remote human identification. Once we achieve this objective, we will work toward achieving an autonomous threat-non-threat discrimination capability. This capability will speed the search process, minimize transmission of false target images, and reduce demands on the remote human operator.

APPROACH

Together with Foster-Miller, Inc. (FMI), we have developed several close-range or contact sensing techniques that exploit electromagnetic properties, shape, texture, impulse response, and image. We plan to review sensor developments in early FY01 to select one or several sensor suites that will be demonstrated during the FY01 sensing demo, planned as part of the 6.3 Very Shallow Water/Surf Zone (VSW/SZ) program. Another partner, Fast Mathematical Algorithms and Hardware, Inc. (FMAH), is conducting analysis of sensor signatures and is developing classification algorithms that fuse multi-sensor data.

Figure 1. Sensor development Lemming fitted with shape profiler

WORK COMPLETED

The following work was completed during FY00. The report[1] documented progress up to spring 2000.

Sensor Development Lemming. To facilitate collection of sensor signatures, the Coastal Systems Station (CSS) has fitted a Lemming vehicle with a magnetic sensor that constrains the vehicle within a small test pen (see Figure 1). We attach sensors to the vehicle, which is set on a random search path within the pen. The vehicle frequently interacts with targets in the pen and approaches them repeatedly from different angles, transmitting sensor signatures via radio to a laptop computer for recording. In this manner, we can collect signatures quickly and efficiently.

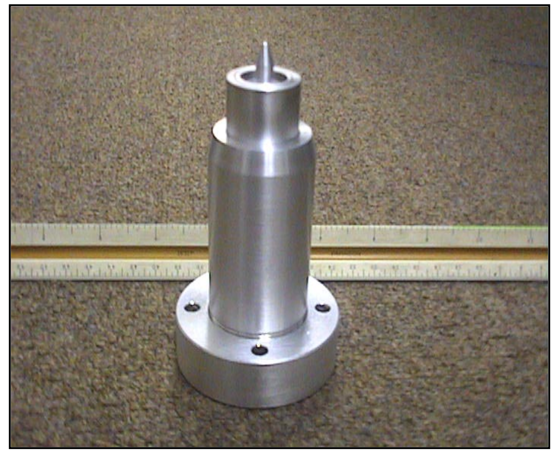

Figure 2. Combined impulse sensor

Impulse Sensing. Impulse or impact sensing is based on the response of target structures to mechanical excitation. If we input a broadband input (a fast rise time pulse or strike), we excite resonances of the target, and these can be used to discriminate between different kinds of objects. The discrimination algorithms applied must be insensitive to variations in damping that can occur from partial burial or biofouling of the targets, as well as normal variations in resonances among targets of a common type.

CSS built and tested the combined striker-microphone impulse sensor shown in Figure 2. This device is a tubular striking mechanism combined with a contact microphone probe, and mounts to the vehicle bumper. Pressing the probe into the target loads a spring driven hammer and releases it to strike the target. The probe design provides an acceleration response that varies less than +/- 2dB from 0.5Hz to 15KHz with over 65dB dynamic range, at $10 per unit. However, data collected against the standard target set revealed inconsistencies in the spectral content from strike to strike. We determined that good coupling between the microphone probe and target was difficult to obtain consistently due to a dependence on orientation of the probe. In addition, resonances in the striker mechanism coupled into the probe and contaminated the target response.

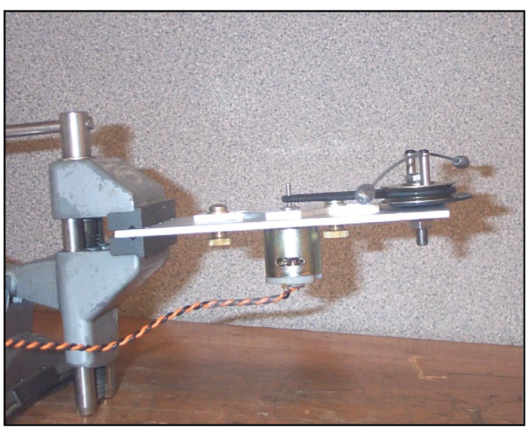

Figure 3. Test flailer mechanism

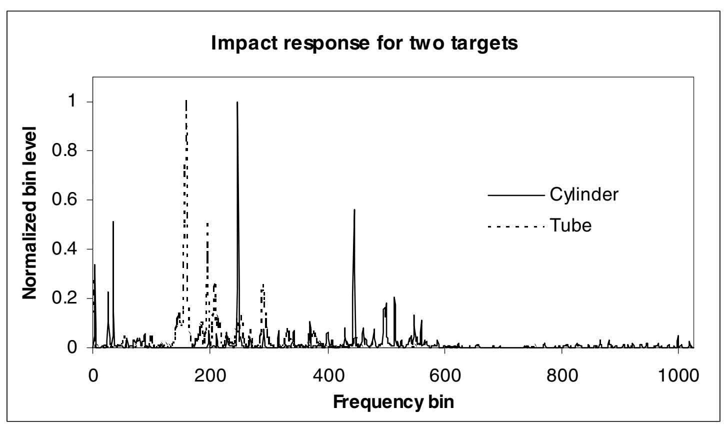

Figure 4. Normalized periodigrams of flail signatures of two laboratory targets

We have built and tested the proof-of-concept device shown in Figure 3 that uses a rotating flailer mechanism to repeatedly tap on the target. A microphone or hydrophone monitors the target response acoustically. This approach avoids requiring the robot to couple a transducer to the target surface, it is forgiving with regard to positioning, and it produces a periodic signal that allows averaging to be applied in the analysis algorithm. In air, the flail approach provides clear and consistent discrimination between different targets, as shown in Figure 4. We are designing a device for signature collection in the sea.

Shape Tracer (Profiler). We have successfully tested a pivoting arm profiler on the Lemming vehicle on land, and we are redesigning the tracer for underwater use[2], shown in Figure 5. The sensor operates by sampling the arm deflection angle as the vehicle travels past the target at constant speed. We can reconstruct the profile of the target from the angle samples, vehicle speed, and sensor geometry. A contact sensor mounted at the arm tip triggers the angle sample recording so that the geometry of the sensor and target is known.

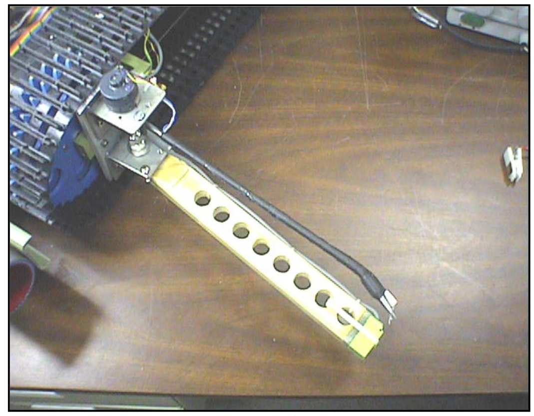

Figure 5. Lemming fitted with profiler and proximity sensor arms

Tests have shown that profiling works well when the crawler has good ground traction and the ground roughness is not greater than several inches peak-to-peak, with distance between major ground peaks not exceeding about 6 inches. Track slippage and bottom roughness introduce noise and distortion to the measurement. Some means of detecting "bad traces" caused by these factors will be needed.

We have shown the ability to identify shape features such as angularity, roundness, roughness, seams, ribs, poles, and flats. The profiler also has utility as an extension of the bumper, providing position of the vehicle relative to the target center. The vehicle can use this information to reposition and to aim the camera toward the target, or to take additional signatures of the target using other sensors. We have used the tracer in combination with a commercial proximity sensor, providing both surface shape and general material type (metal or nonmetal), which is the lower arm shown in the figure. A further extension of the profiling principle was to stack two trace arms vertically and to correlate upper and lower profiles as a metric of target symmetry.

Camera. CSS designed and built a CMOS, gray scale, single-frame image camera that transfers data and commands over an RS232 serial interface[3] shown in Figure 6. While many commercial cameras are available, most require USB interface and all are shipped with drivers for the Windows operating system. In addition, CCD cameras coupled with an image capture board draw significant power. The CSS camera draws under 100mW, and the robot can deactivate the camera when not needed.

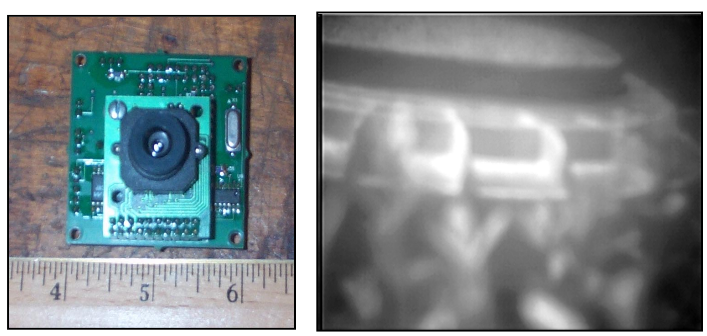

Figure 6. CSS camera and underwater image of practice mine

FMI has assembled a catalog of 200 underwater images taken using a 35mm film camera at three locations – Revere Beach, MA, Scusset, MA, and Duxbury Beach, MA[4]. The images include four different surf zone threat objects. These images represent extremes in visibility of targets under ambient illumination.

CSS has continued studies of optimal illumination techniques for imaging from the crawler. Additional tank testing is scheduled to begin in late September, 2000[5].

Rotating Head Sonar. Marine Sonic, Ltd., working with Foster-Miller, Inc., has tested a 900KHz single beam sonar in a benign dockside environment[6]. By rotating the sonar and pinging at 5.5 pings per degree of rotation, the investigators produced polar maps of the sonar returns. Figure 7 shows bridge piers and other objects present near the dock site. Maximum range for the sonar was 40m under the test conditions.

Pulse Eddy Induction Coil (PEIC). Foster-Miller, Inc. tested a modified Fisher metal detector mounted on a crawler. The sensor detected metal objects out to 1ft. despite the vehicle's components being mostly metal[7].

Texture Sensor. Foster-Miller, Inc. has continued development of a tactile sensor based on a grit covered tube and microphone transducer[7,8] shown in Figure 8. FMI has improved the sensor by adding baffling material, which eliminated a troublesome resonance caused by trapped air in the tube. FMAH has completed analysis of an extensive signature set and has demonstrated the sensor's potential for target discrimination[9].

Gradiometer. CSS continued development of a magnetic gradiometer based on using two triaxial fluxgate orientation sensors separated by a 18.9cm baseline. The approach is to compute a scalar quantity called the gradient contraction. The contraction is a more robust indicator of the presence of a magnetic anomaly (target) than a total field measurement, which can vary depending on how the sensor and target are orientated in the earth's magnetic field. A search for targets using the gradiometer would involve detecting an increase in the contraction number as the vehicle moved along its search path. By following the increasing gradient contraction, the crawler will be led to the target.

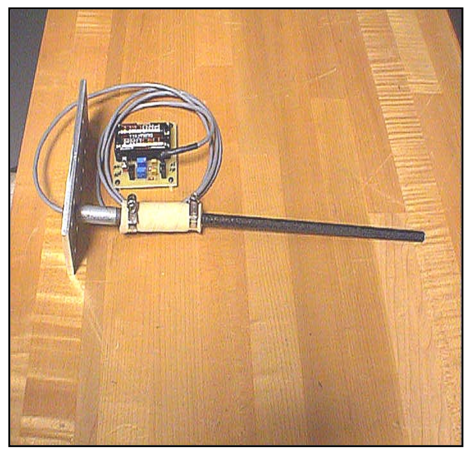

Figure 8. Foster-Miller tactile sensor

A critical requirement will be to reduce the vehicle's signature to less than 0.1Am^2, more than an order of magnitude below that of the current vehicles used. Another requirement is for vehicle motion compensation, and it may be necessary to stop periodically to take field measurements.

A test of the gradiometer concept on a nonmetallic platform detected a 2.7Am^2 target at 3m range. LabView software currently implements the gradient contraction algorithm. Plots of the total field measurements and the gradient contraction clearly show superiority of the contraction method in consistency with regard to signal shape and level as a function of approach angle. These algorithms are reported in Reference 10.

Active Magnetic Sensor. CSS is developing an active magnetic sensor based on magnetoresistive sensor technology[11]. A design for a bench proof of concept device has been completed.

Auxiliary Sensors. CSS has built several auxiliary sensors[12], including a bumper sensor for obstacle avoidance and for proud target detection by collision. The bumper consists of a hollow, silicone rubber tube fitted with a piezoelectric cable that senses deflections on collision with a target. We have developed a metal detector that fits within the bumper for determining the presence of ferrous or nonferrous metal.

We have prototyped an Acoustic Avoidance System (AAS) system that enables the crawlers to avoid collisions when their search areas overlap. The system operates by transmitting a 30KHz acoustical signal periodically and listening for the signals of other crawlers between pings. For land use, the GPS clock controls ping timing. Each crawler implements a specific fixed delay following each clock tic before it emits a ping, thus avoiding transmit collisions. If the receiver detects a ping from another vehicle, it stops and waits silently until the other vehicle moves out of detection range.

RESULTS

A selection of sensors is now available for down selecting sensor suites for demonstration in FY01. We may select several suites to demonstrate lane exploration and exhaustive lane mapping. The initial goal will be detection of proud targets and transmission of a picture of the target for human identification. A lane exploration sensor suite would include more expensive, long-range sensors such as the Marine Sonic, Ltd. sonar, together with a camera. A sensor suite for lane mapping would likely include multiple close-range sensors and camera.

For the near term, the most promising sensors are those that have been demonstrated, including the bumper and shape tracer, camera, PEIC, and tactile sensors. The sonar and magnetic sensors offer the greatest potential detection range. However the sonar is an expensive device and although it is suitable for a small number of lane exploration vehicles, it will be impractical to mount the sonar on every vehicle in a large crawler swarm. The magnetic sensors will require reducing the vehicle's self-signature, and implementing motion compensation, both of which will be costly. We will continue development of the magnetic sensors into FY01, and if promising, we will address the vehicle signature issue.

IMPACT/APPLICATION

The sensors will enable exploration and mapping of the sea bottom in the surf zone, where conventional long-range sensors will not operate. By exploiting many target features at close range we hope to provide autonomous discrimination between threat targets and clutter, reducing waste of limited transmission bandwidth through the water.

TRANSITIONS

The Surf Zone Reconnaissance Project directly supports the 6.3 VSW/SZ Program, which is demonstrating unmanned vehicle technologies applied to the reconnaissance mission in the VSW and surf zone.

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